Satellite Observation of Surface Forcing over the Warm Pool

W. Timothy Liu*, Catherine Gautier+, Martin Landsfeld+, and Wenqing Tang*
* Jet Propulsion Laboratory, California Institute of Techonlogy, Pasadena, CA 91109
+ University of California, Santa Barbara, CA 93111

ABSTRACT

Daily variations of wind and solar forcing derived from satellite data were compared with sea surface temperature and temperature tendency during the Tropical Ocean Global Atmosphere - Coupled Ocean Atmosphere Response Experiment. The correlation between solar flux and temperature tendency is positive indicating that the solar forcing is a significant factor in daily sea surface temperature change. Daily change in sea surface temperature does not have significant effect on incoming solar flux. Wind speed is negatively correlated with sea surface temperature and temperature tendency, underscoring the need to understand the feedback mechanism between wind forcing and thermal response.

INTRODUCTION

There has long been strong interest in relating sea surface temperature (SST) to surface wind and thermal forcings in the tropical oceans. Over these warm waters, numerical experiments have demonstrated that small change to SST would significantly affect global climate change. The warmest water is found in the tropical western Pacific and eastern Indian oceans, called the warm pool. Over this area, SST is relatively uniform between 28°C and 30°C. The factors which maintain this high temperatures are controversial. It has been postdated that cirrus cloud is the dominant natural thermostat which keeps the temperature in the warm pool at an equilibrium temperature. The inference is that any increase in sea surface temperatures would greatly increase cloud cover and shut off solar heating (e.g., Ramanathan and Collins, 199 1). There is rdso an alternative hypothesis on evaporation as the natural thermostat; any increase in SST would greatly increase the capacity of the atmosphere in holding moisture and, therefore, would increase evaporative cooling of the ocean (e.g., Newell, 1979; Hartman and Michelsen, 1993). Liu and Gautier (1990) and Liu et al. (1994), using monthly mean satellite data, found no strong negative correlation between the seasonal change of SST and solar flux implying the seasonal change of solar heating is not controlled by sea surface temperature but by the solar incident angle. Significant positive correlation are found between solar flux and temperature tendency (temporal derivative of SST) over most of the global ocean, implying that seasonal change in upper ocean heat balance is strong affected by solar heating. The exception u in the equatorial wave guide where ocean dynamics may play a more important role. They also found ubiquitous negative correlations between monthly evaporation and SST (and temperature tendency). Liu et al. (1994) suggest that the negative correlation may be due to a third factor, wind speed, which correlates positively with evaporation (according the bulk aerodynamic formula) but is found to be negatively correlated with SST and temperature tendency.

The recent debate on natural thermostat is based on analysis of low frequency variabilities, from seasonal to decadal. However, large high-frequency fluctuations caused by intermittent and organized convection have been observed in the warm pool. Using monthly-moan parameters in estimating correlation neglect the.so high-frequency variances. Ono of the objectives of the Coupled Ocean Atmosphere Response Experiment (COARE) of the Tropical Ocean and Global Atmosphere (TOGA) program is to examine the effect of this fluctuation affects large-scale and long term averages (TOGA-COARE SWG, 1989). In study, daily surface solar flux and wind vectors were derived from spaceborne sensors and their temporal variability is compared with those of SST and its derivatives during the TOGA-COARE.

WIND AND SEA SURFACE TEMPERATURE

The daily SST were provided by the TOGA COARE International project Office (D. Carlson, personal communication, 1993); they were computed by averaging measurements from a network of eight ships in the Intensive Flux Array (IFA) during the experiment. The temperature tendency is approximated by the gradient of the linear *regression* through three day of SST data. Ocean surface wind vectors were derived from observations of the microwave scatterometer on ERS 1 using the geophysical algorithm by Freilich and Dunbar (1993). Daily fields of the wind vectors over global oceans were computed from these scatterometer wind, using a successive correction method (Gadin, 1963). They arc averaged over an area 4°S-1°N, 150°E-158°E, covering the IFA.

SURFACE SOLAR FLUX

The method used to compute the surface solar radiation flux, originally developed by Gautier et rd. (1980), is based on simple, physical modelin of the most important radiative processes occurring within the atmosphere, namely scattering and absorption b molecules, clouds, and aerosols. Since variability of surface insoradon results primarily from changes in solar zenith angle and cloudiness, the method focuses on determining the effect of clouds on surface solar radiation flux since solar zenith angle can be computed accurately from simple formulas. The method accomplishes this by computing cloud albedo, th governing cloud parameter, from GMS VISSR measurements in the visible. The repeat coverage of the GMS VISSR data (one observation every 30 minutes) allows art adequate sampling of the diurnal cloud variability.

Images compood of 888 x 444 pixels centered on tho equator and 155°E and covering a region of approximately 400,000 km^2 have been acquired every 30 minutes from GMS-6 ovar the TOGA-COARE area from the University of Hawaii (courtesy of P. Flament). These data have been averaged over 5 x 5 km^2. The first step in the computation procedure is to calibrate the data. We have used the preflight calibration coefficients *(gain and* offset) but adjusted the gain for a drift in dine. This gain adjustment has been obtained by comparing results from our computations with surface solar flux measurements at a number of islands. The gain has been computed so that to minimize the bias between the satellite estimations and these surface measurements. The next step is to estimate the minimum brightness Of the surface in clear conditions in order to determine a threshold for cloud conditions. This minimum value defines a threshold (taken a fow counts higher) that is used to classify each GMS VISSR (Visible Infrared Spin Scan Radiometer) pixel as clear or cloudy. By comparison with a procedure based on a fixed surface albedo, this procedure allows us to detect clouds in regions of sunglint. Once the pixel's nature (clear or cloudy) has been determined, we apply clear and cloudy sky radiative transfer models accordingly. In clear sky conditions, surface insolation is expressed as:

$$I_o = S_o (r/r_o)^2 \cos\theta \exp(-C1/\cos\theta)/(1-C2A_s) \, X \exp[-a_o(u_o/\cos\theta)^{b_o}] \exp[-a_w(u_w/\cos\theta)^{b_w}] \quad (1)$$

where S_o ia the solar constant, r/r_o is the ratio of actual to mean earth-sun distance, θ is solar zenith angle, u_o and u_w are ozone and water vapor amounts respectively, A_s is surface albedo, and a_o, b_o, a_w, b_w, C_1, and C_2 are coefficients (C_1 and C_2 depend on the type and concentration of aerosols). The term $1-C2A_s$ accounts for photons that have sustained multiple surface reflections. Ozone and water vapor amounts are specified from climatology and A_s is obtained by solving the following equation:

$$A_{sat}(B_{min}) = a + (1 - a)(1 - a_1)(1 - a'_o)A_s \quad (2)$$

whet-e A_{sat} is the albedo measured at the satellite (the surface is assumed to reflect solar radiation isotropically), B_{min} is the minimum brightness, a and a_1 arc direct and diffuse reflection coefficients, respectively, and a'. characterizes ozone absorption. Eq. (2) simply states that A_{sat} is the sum of an atmospheric component (photons reflected back to space without surface reflection), and the signal reflected by the surface and diffusely transmitted to space.

In cloudy sky conditions, the clear sky formulation is modified to account for reflection and absorption by clouds which are assumed to occur in one layer. Cloudy sky insolation is therefore given by:

$$I_c = I_0(1 - A_c - a_c)/(1 - A_c A_s) \qquad (3)$$

where A_c is cloud albedo and a_c is cloud absorption. The denominator represents the effect of multiple reflections between the cloud and the surface. This effect is small over the ocean. Cloud albedo is obtained by solving the following quadratic equation:

$$A_{sat} = a + (1 - a)(1 - a_1)(1 - a'_o)A_c + (1 - A_c - a_c)2(1 - a_1)(1 - a_o)A_s \qquad (4)$$

where A_{sat} is the top-of-atmosphere albedo, assuming that clouds reflect solar radiation isotropily. This equation, in fact, gives A_c in the GMS VISSR solar channel (mostly wavelengths in the visible). We assume that Ac takes the same value in the spectral interval of total insolation.

Preliminary comparisons with surface solar flux data at Kapingamarangi show that the clear conditions are extremely well reproduced by our method (within a 2-3 %) and that in all conditions, our computations have an uncertainty of about 10% of the surface measurements. The biases has been minimized through the calibration procedure. The surface solar flux is then averaged over the same area as the surface wind speed.

RESULTS

The time series of daily SST, temperature tendency, surface solar flux, and surface wind speed are compared in Fig. 1. The best contemporary correlation is between the temperature tendency and the solar flux. For the 55 pirs of data, the correlation coefficient is 0.51, which is significant at 99% level if the data pairs are independent from each other. The positive correlation infers that the change of uper ocean heat balance in the daily time scales is significantly influenced by solar forcing at the surface. This is different from the month mean data examined by Liu et al. (1994) who found low correlation in the equatorial ocean. The correlation between 60 pairs of SST and solar flux is -0.28. The negative correlation may imply that increase in sea surface may

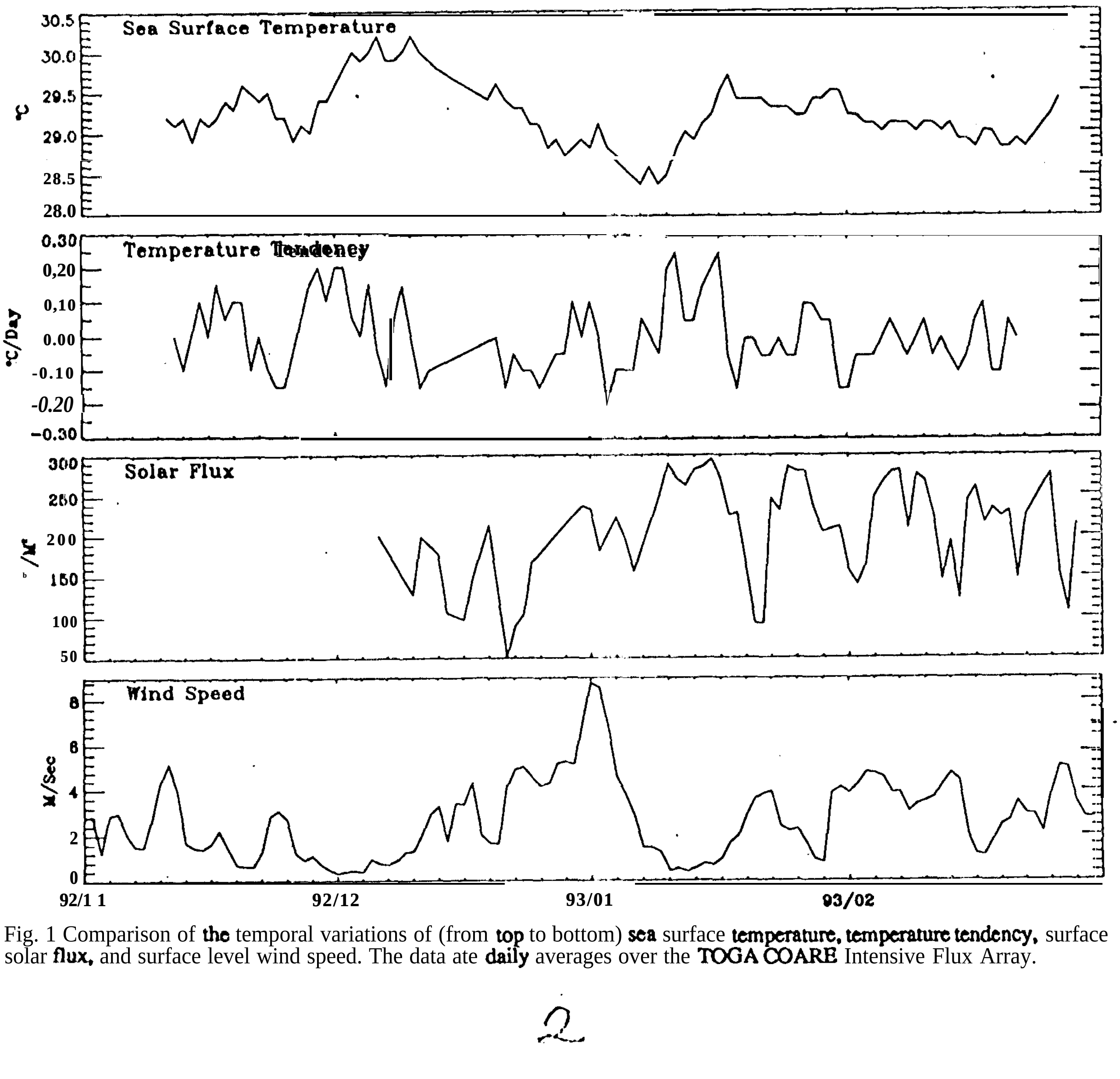

Fig. 1 Comparison of the temporal variations of (from top to bottom) sea surface temperature, temperature tendency, surface solar flux, and surface level wind speed. The data ate daily averages over the TOGA COARE Intensive Flux Array.

decrease solar heating through cloud cover, but the coefficient is too low to be significant at 99% 10VCI Liu et al. (1994) also found low correlation in tho seasonal variation, Tho wind speed is negatively correlated with SST and temperature tendency.

The correlation coefficients are -0.43 between 93 pairs of wind speed and temperature tendency and -0.32 for 99 pairs of wind speed and SST. In both cases, tho correlations coofficients are significant at" 99% level, assuming inpe ndent data. The negative correlations are similar to those for monthly means examined by Liu et al. (1994) and similar reasoning may apply. Increase in wind and, therefore, the available kinetic energy may change thermocline depth and entrainment intensity. Increase in wind may also increase evaporative cooling. Convective activities may also increase with SST and cause surface wind convergence and low wind speed.

CONCLUSION

The solar flux shows stronger influence on SST over the warm pool at the daily time scale than at the monthly time scale. SST has little influence on solar flux at daily time scales, in agreement with previous results for monthly data. Wind speed is found negative correlated with both SST and temperature tendency in agreement with monthly data. Only very preliminary results are presented in this study. Further analysis With mom supporting data from TOGA COARE is anticipated

Acknowledgment

This study was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with National Aeronautics and Space Administration (NASA), and at the University of California at Santa Barbara. It was supported, in part, by the Interdiscipline Science Investigation of the Earth Observing System and Earth System Modeling and Global Analysis Branch of NASA. We are grateful to David Carlson and Pierre Flament for providing tho data over TOGA COARE.

References

Freilich, M.H. and R.S. Dunbar. "A preliminary C-band scatterometer model function for the ERS-1 *AMI* instrument." in Proc. Fiit EM-I symposium, 1993, pp. 79-84.

Gandin, L.S. *Objective Analysis of Meteorological Fields. Leningrad:* Hydromet. Press, 1963.

Gautier, C., G. Diak, and S. Masse "A simple physical model to estimate incident solar radiation at the surface from GOES satellite data." *J. Appl.* Meteor. 19 (1980) 1005-1012

Hartman, D.L., and M.L. Michelson. "Large-scale effects on the regulaon of tropical sea surface temperature. " *J. Climate* (1993) 2049-2062.

Liu, W.T. and C. Gautier. "Thermal forcing on the tropical Pacific from satellite data." *J. Geophys. Res.* 95 (1990) 13569-13580.

Liu, W.T., A. Zhang, and J.K.B. Bishop. "Evaporation and solar irradiance as regulators of sea surface temperature in annual and interannual changes" *J. Geophys. Res.*, (1994) accepted for publication.

Newell, R.E. "Climate and the ocean" *Amer.Sci* 67 (1979) 405416.

Ramanathan, V., and W. Collins. "Thermodynamic regulation of ocean warming by cirrus clouds deduced from observations of the 1987 El Niño" *Nature* 251 (1991) 17-32

U.S. TOGA COARE Science Working Group. *TOGA COARE Science Plan.* Boulder: Univ. Corp. for Atmos. Res, 1989.